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The Representation of Psychological Space

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This symposium brings together a set of research efforts that have a common focus on the representation of psychological space within a cognitive architecture, but also differ in the basic ways in which space is represented and used in problem solving. Some of the research programs are motivated by theoretical and architectural concerns, while others have applied interests. The efforts vary in the scientific discipline with which they are most closely associated and in the extent to which they are multi-disciplinary. They involve a range of methods from artificial intelligence, cognitive psychology, experimental psychology, and neuroscience.

To facilitate comparison, insight, and discussion, we have defined a core set of dimensions to be addressed at the end of each presentation. These dimensions (A-C below) focus on functionality, substantive questions in spatial cognition, and important empirical phenomena. This presentation framework will make it easier to identify the scope and limitations of what each presenter has accomplished, encourage a more accurate assessment of the state of the science in spatial cognition, and improve the audience's ability to compare and contrast some of the approaches adopted for conducting research on this important topic.

(A) How do the different models/architectures support each of the following, if at all?

- Spatial localization of objects relative to self
- Spatial relations among objects other than self
- Navigation
- Imaginary spatial problem solving (including mental rotation, etc)

(B) What is the relationship between visual and spatial representational systems?

(C) How does the representational framework most strongly influence spatial problem solving?

Segmented Spaces: Coordinated Perception of Space in ACT-R

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Our subjective experience of the spatial world around us appears to be unified and unistructural---i.e., it feels as if there is one world out there around us. Yet there is clear evidence that our brains represent the visual/spatial world around us in several different ways: in different places in the brain, using different representational schemes, with different strengths and weaknesses, supporting different kinds of tasks. Based on a variety of neuroscience, developmental psychology, and computational considerations, we have developed an extension to ACT-R called ACT-R/S, which adds two spatial buffers (configural and manipulative) to ACT-R, beyond the current visual buffer, for example. We find that computationally it is crucial to have considerable integration and cross-talk between the three visual-spatial buffers, and only in special boundary cases will one see evidence of one buffer appearing to work alone in a given task. Thus, our framework explains both the subjective experience of unistructural space and the scientific data of separate representations of space. We will present simulations demonstrating the need for the integration process and simulations of a commonly discussed boundary case in developmental psychology.

FORMS: A Framework for Modeling Spatial Cognition

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This talk describes a unified theoretical framework for human spatial cognition called FORMS (frame of reference-based maps of salience) along with empirical studies conducted within the framework and computational models of those results. The theory maintains that spatial cognition is an elementary brain function that involves multiple unique brain systems. Space is represented in the mind not once but multiple times, not unified but segmented. Each representation is a salience map with a distinctive frame of reference. It is believed that this theory has solid neuroscience support, is consistent with the general findings that the mind's views of space are often segmented, relative, and distorted, and provides a theoretical foundation for computational modeling of human spatial cognition. The framework was used to explore two fundamental issues in spatial reasoning: the role of spatial location in the binding and later reintegration of object features; and the encoding and use of spatial object-to-object relationships. An extension to Act-R/PM, called Act-R/PMO (O for oriented), was implemented to explore architectural encoding of object locations and object-to-object spatial relationships, and to support the general postulates of the framework. The resulting computational models provide a good fit to the empirical data and begin to clarify important aspects of spatial information representation including the underlying frames of reference and early vs. late computation.

Measurement and Modeling of Visuospatial Working Memory

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Visuospatial working memory (VSWM) is the set of cognitive processes used to visualize the locations of things. VSWM is thought to be ubiquitous in everyday cognition, from understanding route descriptions to rearranging furniture. However, scientific measurement of VSWM is difficult. Many tasks that seem to require spatial visualization can in fact be performed using other strategies. We describe a measurement technique, Path Visualization, which we believe requires the use of VSWM. The Path Visualization task yields accuracy and reaction-time data under conditions of large VSWM loads. Initial data from this task suggest that the capacity of VSWM is limited by a process that is sensitive to spatial proximity. A useful preliminary hypothesis is that these proximity effects occur because VSWM computations take place in a 3D spatially isomorphic mental projection area--a 'mental holodeck'. We developed a simple spreading-activation model (in MATLAB) of the mental holodeck. This model can account for some key qualitative effects in the accuracy data, which suggests spreading activation as a promising explanatory mechanism. We then developed models of Path Visualization in ACT-R that explore different mechanisms for explaining the empirical results.

Spatial Processing Requirements for Navigation and Interaction with Cognitive Agents in a 3-D Interior Space

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Our goal is the development of cognitively plausible agents in virtual simulations of urban combat in closed interior spaces such as buildings. The models for these agents, developed in the ACT-R cognitive architecture, must be able to navigate inside these buildings and interact with each other and with human trainees in a way that provides the latter with a meaningful and challenging training experience. This requires a representation that is both sufficient for the task and minimally computationally demanding due to the realtime nature of the task. The compact representation we have used that affords this behavior includes aspects of egocentric and allocentric representations. A global allocentric representation of space is constructed from an off-line interaction of an independent mapping agent with the simulation environment, a commercial game engine called Unreal Tournament. When the agents navigate the on-line simulation environment, an egocentric representation of the surrounding space is extracted from the allocentric representation and made available to each agent. That representation includes fixed parts of the environment such as corners, doors and walls, as well as dynamic parts of the environment such as other agents and sounds, organized in a structured semantic network. The agents use that representation to navigate the space and reason about it to plan future actions such as setting an ambush for their opponents or planning to enter an unexplored room. The accumulation of these egocentric representations in memory gradually yields a cognitive map of the space. This resulting cognitive map shares characteristics of both egocentric and allocentric representations allowing agents to navigate both within a particular space (e.g., moving to the corner of a room to the left of a doorway) and between spaces (e.g., retreating to the entry point in the building). This representation, which is at times memory-based and at times directly-perceived, combined with established tactics for urban combat, enables the agents to demonstrate plausible behavior consistent with human behavior in these environments.

Playing hide and seek: How much spatial cognition is needed?

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Young children clearly have a sense of space and use it for many tasks. However, their use of spatial cognition may be constrained by other developmental issues. For example, previous research has suggested that 3-4 year old children do not have a well developed sense of perspective-taking, but 3-4 year olds are able to play a credible game of hide and seek, which seems to require both perspective-taking and spatial cognition. We suggest that very little perspective-taking ability and only very rudimentary spatial cognition is actually needed to play hide and seek. We have implemented a computational cognitive model that plays hide and seek within these constraints. Thus, it is able to reason about objects in simple spatial ways ("Does this object have an "underneath?") but not in more complex ways ("Is that object big enough for me to hide behind it?") and learn to play a credible game of hide and seek. Our model makes qualitative improvements in short time-frames (over a few games).

We have taken our computational model and put it on a physical robot. The robot uses its own sensors to examine a room and find objects. Our model then makes a decision on where to hide, and the robot moves to the appropriate location. Speech is used to communicate with the robot, giving it feedback on its hiding place, as well as suggestions on playing the game (i.e., "You may not want to hide out in the open."). We suggest that our model is able to play hide and seek the same way a 3.5 year old child plays.